NTNU
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Using Virtual Reality to increase technical performance during rowing workouts

Ricard Vivo Montero

Master of Science in Electronics
Submission date: April 2018
Supervisor: Andrew Perkis, IES
Co-supervisor: Sebastian Arnt, IES

Norwegian University of Science and Technology
Department of Electronic Systems

Abstract

Technology is advancing rapidly in virtual reality (VR) and sensors, gathering feedback from our body and the environment we are interacting in. Combining the two technologies gives us the opportunity to create personalized and reactive immersive environments. These environments can be used e.g. for training in dangerous situations (e.g. fire, crashes, etc), or to improve skills with less distraction than regular natural environments would have. The pilot study described in this paper puts an athlete who is rowing on a stationary rowing machine into a virtual environment. The VR takes movement from several sensors of the ergo-meter and displays those in VR. In addition, metrics on technique are being derived from the sensor data and physiological data. All this is used to investigate if, and to which extent, VR may improve the technical skills of the athlete during the complex sport of rowing. Furthermore, athletes are giving subjective feedback about their experience comparing a standard rowing workout, with the workout using VR. First results indicate better performance and an enhanced experience by the athlete.

Sumario

La tecnología avanza rápidamente en la realidad virtual y los sensores recogen los comentarios de nuestro cuerpo y del entorno en el que estamos interactuando. La combinación de las dos tecnologías nos brinda la oportunidad de crear entornos inmersivos reactivos y personalizados. Estos entornos se pueden usar, p. para el entrenamiento de situaciones peligrosas (por ejemplo, incendios, choques, etc.) o para mejorar las habilidades con menos distracción de lo que los entornos naturales normales tendrían. El estudio piloto descrito en este documento pone a un atleta que rema en una máquina de remo estacionaria en un entorno virtual. El VR está tomando movimiento de varios sensores del ergo-metro y los muestra en VR. Además, las métricas de la técnica se derivan de los datos del sensor y los datos fisiológicos. Todo esto se usa para investigar si, y en qué medida, la RV puede mejorar las habilidades técnicas del atleta, durante el complejo deporte del remo. Además, los atletas están dando su opinión sobre su experiencia en comparación con un entrenamiento de remo estándar con el entrenamiento usando VR. Los primeros resultados indican un mejor rendimiento y una mejor experiencia del atleta.

Acknowledgement

To my supervisor Andrew Perkis, who got me involved in this project as an exchange student.

To my co-supervisor Sebastian Arndt who helped me organize the work on this project, and also who gave me valuable guidance.

To my collaborators from TUB, Jan-Niklas Voigt-Antons, Bruno Kortowski, Uliana Sirotina and Lukas Tetzlaff who made working together really easy. A special mention to Lukas, for his patience and late night skype calls to help me in some programing issues.

To the NTNUI Rowing team for taking part in this project. All the feedback and opinions given were very valuable for this project and helped us to understand the needs of experienced rowers.

To the companies Augletics and SweetZpot, for taking part in the project and giving us all the facilities regarding their products as access to their source code, to their private APIs, etc.

To all people from the Signal Processing group, for your short talks at the cafeteria and smiling at me when crossing each other on the corridor. Working in this atmosphere makes the work easier.

Finally, to NTNU, for giving me the opportunity to undertake a Master thesis as my Bachelor’s Thesis during my exchange program.

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Abbreviations.

3D	3 Dimensions
AR	Augmented Reality
E-sports	Electronic Sports
FSS	Flow State Scale
HD	High Definition
HDM	Head Mounted Display
IP	Internet Protocol
NTNU	Norwegian University of Science and Technology
QoE	Quality of Experience
VoIP	Voice over IP
VR	Virtual Reality

1. Introduction

1.1. Immersion in videogames, media and storytelling

The evolution of videogames has always been focused on offering a more immersive experience, with better graphics, better sound, etc. But the presentation of Nintendo Wii in 2006 became a new stage for the immersion in sports videogames. Nintendo Wii allowed the user to play with movement controllers and it was the first console which brought such an experience of the sports field to your living room. After Nintendo Wii another gadget appeared in the industry: Kinect. This smart camera was able to detect the body movements and to interpret those movements as input signals to control the videogame.

We may also see new sports emerge that are totally based on VR and its sister technologies, augmented reality and mixed reality. E-sports have been around for a while, although many would argue that video games cannot be counted as sports. But with titles such as Pokémon Go and Racket: Nx, which are integrating video-gaming elements and physical exercise, it may not be long before games that integrate AR/VR technologies become fully professional sports.

With the launch of the Nintendo switch last year, we have begun to see the social potential of immersive videogames. A clear example is the ARMS videogame, which allows multiplayer arcade boxing matches using controllers as boxing gloves.

Immersive media is not new concept. Emerging technologies such as VR and AR, as we currently know them, are part of an evolutionary path making media more immersive.

Figure 1 - Evolution of storytelling

Humanity has always looked for ways to draw the audience in deeper, whatever the media. In many cases, storytellers have utilized the use of technology to achieve this goal. It is not about telling better stories, (since the development of our cultural tools has not brought us better artists) but rather about surprising the audience and making them feel part of the story. Technology has given us ways to improve the experience of consuming a narrative, allowing stories to be told in more immersive ways.

Historically, different cultures incorporated moving images and other visual elements, such as acting or dance, to improve immersion in storytelling. This was the seed that would later be known as theater. The first 3D movies tried to break the wall of the screen itself, merging real worlds with narrative worlds.

With the arrival of the second generation of stereoscopic 3D, the precision provided by this technology was improved. Consequently, it gave the audience an immersive experience without having the projection problem of the primitive anagram and double band. In addition, the surrounding digital-audio and visual effects generated by the computer were added to this technological generation.

1.2. VR and AR:

Both VR and AR are different technologies. Virtual reality is a digital world that is entered through a head mounted display (HMD). Through these HMDs, we have a 360-degree 3D visual experience and we can explore narrations through our physical movement. On the other hand, there is Augmented Reality, which is a narrative entering into our own world through graphics, holograms or other virtual media.

We could define virtual reality as a natural extension of stereoscopic 3D, although the AR is beginning to break the barriers to reach the general public. Many can find it uncomfortable to wear devices on their heads, and also, these devices isolate the user from a social environment. It is for this reason that when we think about developing applications in virtual reality, it is very important that there is a social value in it, since humans tend to respond better when they can share their active experiences with their social circle.

It must be considered that VR markets are trying to become more accessible to the general public. A few months ago, the New York Times newspaper gave all its subscribers the Google Cardboard (Figure 2) which allowed users to have access to experience the Virtual Reality by only using their smartphone and a piece of cardboard.

Figure 2 - Google Cardboard

1.3. How virtual reality is transforming the sports industry

Sports is one of the fields where the use of technology is starting to be used more effectively and aggressively. Elements, such as the Hawk-Eye in tennis, or different holograms in a football match, have accustomed us to the presence of augmented reality (AR) in sports.

Not only AR is present nowadays in sports, but also VR, starting for fan enhancing.

1.3.1. Viewing sporting events in VR

Lately 360-degree cameras are being used to capture and broadcast sporting events in virtual reality. This allows fans to see their favorite alters as if they were in the stadium, without leaving the comfort of their homes, and without having to spend money on tickets or flights.

NextVR (Next VR, 2018) is a new virtual reality transmission startup dedicated to covering the professional sports broadcast, enhancing the experience of the fans. This company has already covered some of the major sporting events with VR transmission, such as the opening game of the 2015 NBA season between Golden State Warriors and New Orleans Pelicans.

In the repertoire of events broadcast, you can also count several NBA and NFL games, plus the Super Bowl, a NASCAR race and a couple of NHL games.

1.3.2. Viewing the action from the player's perspective

It can be expected that much will change in the coming months and years, including interactivity, stats and additional info added to the display, as well as on-player camera feeds enabling you to view the action from the eyes of your favorite athlete.

We have already seen progresses in this field, for example, last year a Spanish startup known as FirstV1sion (FirstV1sion, 2018) used its smart wearables to offer player perspective video feeds at several sporting events, including a Euroleague basketball match. The garment contains an embedded HD camera and a microphone, plus additional sensors that monitor player health stats.

1.3.3. Dealing with the social shortcomings

One of the strongest arguments against the use of VR in consuming sports content is the fact that it takes away from the social experience of attending a live event. Part of the pleasure of watching a game is having the company of family and friends. VR headsets, alas, only offer a solitary experience. The acquisition of the Oculus by Facebook is partly credited with fixing this shortcoming.

Tech startup Virtually Live (Virtually Live, 2018)aims to tackle the social element with its VR offering. It displays a virtual reconstruction of the stadium and players in near-real time, and fans are invited to step in and view the environment from any viewpoint they want.

However, Virtually Live adds social functionality to the mix. Fans appear as avatars and can interact with each other through VoIP. The firm wishes to thus make it more compelling for people to get together and watch games in VR.

1.3.4. Using VR to train teams

Professional teams have long used the study of films to examine their own performance or assess opponents. But with the vantage point being much different from what a player experiences during the game, the results are not always optimal.

Now, coaches and players train better by watching and experiencing plays again and again in virtual reality. This is the idea that, along with a $50,000 investment, got VR startup STRIVR Labs off the ground one year ago.

STRIVR (STRIVR, 2018) produces VR training videos shot from the player’s perspective of the action during practices. It then enables players to receive realistic, repetitive training by visualizing through VR headsets situations they will face on the field. For instance, quarterbacks can review the options and opportunities they missed by going through a play several times and reviewing each of their teammates’ positions.

1.4. VR experience as a method to improve sports performance:

Here, so-called exergames put the focus on the gaming engine and thus rather have the goal of motivating people to exercise, where the fun and motivating part is more important than coaching on perfect technique or optimal performance. In addition, many approaches in VR sports try to simulate realistic sports environments and put the focus on improving technique and adding more realistic conditions for the athlete. However, improving the fun during workout is definitely an important aspect. Appelbaum & Erickson (2016), give a review of sports vision training using digital training techniques, mentioning that athletes rely greatly on vision, and visual training for their sports such that they can improve their performance. In their review they highlight three naturalistic sports training approaches, one of them being simulations to recreate the sporting environment in virtual reality. While this is a growing market especially for amateurs, only very limited research has been performed in this area which can show an increase in performance. Shepherd et al. (2018) designed a virtual velodrome and let non-elite cyclists evaluate their experience during cycling in the VR. Their results showed an increase in behavioral fidelity, as well as performance, which included the concept of presence.

In this project, I present a study within indoor-rowing. Where we explore how a VR environment is affecting the performance of athletes over a regular indoor-workout. The goal of this investigation will be to test if professional athletes will improve their performance by using a more immersive experience, in this case, a VR rowing simulator using HTC Vive headset display and a rowing machine from Augletics® plenty of sensors.

So, will it be possible to improve the sportive performance using an immersive experience as VR?

Will it be possible to increase the quality of experience during workouts?

2. Specifications

2.1. Description of the project.

The aim of this project was to answer the following question: Would be possible to improve the sportive performance of athletes using VR?

First of all, we need to decide which sport we want to focus on. This sport should be able to be tested in a closed room and it should also be possible to objectively test the performance of the athletes.

The chosen sport for this project is rowing. Rowing performance can be easily tested in a closed room as the HTC Vive room setup requires. Rowing in an ergometer in a gym is a monotonous and repetitive exercise which can easily become boring. These arguments fit perfectly in this project, which will try to improve the motivational state of the participant while also improving their technique.

Rowing on an ergometer also can give us some metrics of technique performance of the athlete, which is a great value for this project.

2.2. Hardware description.

2.2.1. The rowing machine:

The ergometer used is this project will be the AUGLETICS Eight. This ergometer from Augletics® is made from professional rowers and provides a realistic feeling like rowing on the water. The rower can feel the acceleration in every stroke. In addition, this ergometer includes plenty of sensors which produces data that is used to calculate

Figure 3 - Augletics Eight ergometer

different parameters and metrics about the performance of the rower, while showing it as a Digital Couch on the screen.

Thanks to the collaboration of Augletics® in this project, we have been provided with access to their API, further enabling access to all this data. We will use this data in two purposes:

- Input data: The VR scenario will need some input data from the ergometer as speed, stroke power and distance rowed, to move all the VR environment according to the real movement on the rowing machine.

Figure 4 - Digital Couch

- Performance Data: The digital couch uses different sensors of the machine to calculate the technique executed in each stroke, which will be relevant while testing.

2.2.2. The breathing sensor:

This project also requires a biological sensor, as it would be interesting to compare the breathing patterns between both VR and non-VR scenarios.

Figure 5 - SweetZpot corportative logo

In this case, the sensor used is the Sweetzpot® breathing sensor. This breathing sensor provides us with several points of data as flow, which includes the amount of air inhaled in every breath, or the number of breaths/min. This last data is most interesting for rowing because a good synchronization between the stroke and the breath will end up leading to a better technique.

This project was also in collaboration with the Sweetzpot® company, which is specialized in this kind of sensors for rowing.

2.2.3. The VR setup: HTC VIVE

The VR display used in this experiment is the HTC Vive, a virtual reality headset developed by HTC and Valve Corporation. The HMD uses "room scale" tracking technology, allowing the user to move in a 3D space, using motion-tracked handheld controllers to interact with the environment. This feature is the most important for this project due to the fact that we will have a rowing machine standing in the middle of a room. The HTC Vive room set consists of three different elements:

- The Vive headset, which is the head mounted display and it provides with a 110 degree field of view. The device uses two screens, one per eye, each having a display resolution of 1080x1200. In addition, the HMD has multiple sensors. The headsets outer-shell has divots, and inside these divots are dozens of infrared sensors that detect the base stations to determine the head set's current location in a space. Other sensors include a G-Sensor, gyroscope and proximity sensor.
- Vive Controllers: The wireless controllers are the user´s hands in virtual reality, making a more immersive experience for the user. Across the ring of the controller are 24 infrared sensors that detect the base stations to determine the location of the controller. The Steam VR Tracking system is used to increase the connection of the controller by giving wireless feedback of 360 degrees to the host in real time.
- Vive Base Stations: Also known as the Lighthouse tracking system are two black boxes that create a 360-degree virtual space, up to a 15x15 foot radius. The base stations emit timed infrared pulses at 60 pulses per second that are then picked up by the headset and controllers with sub-millimeter precision.

So, with these characteristics the plan is to set up a room with the base stations and the rowing machine in the middle of this room, using the controllers as calibrators for the rowing machine. The VR setup can be seen in Figure 6.

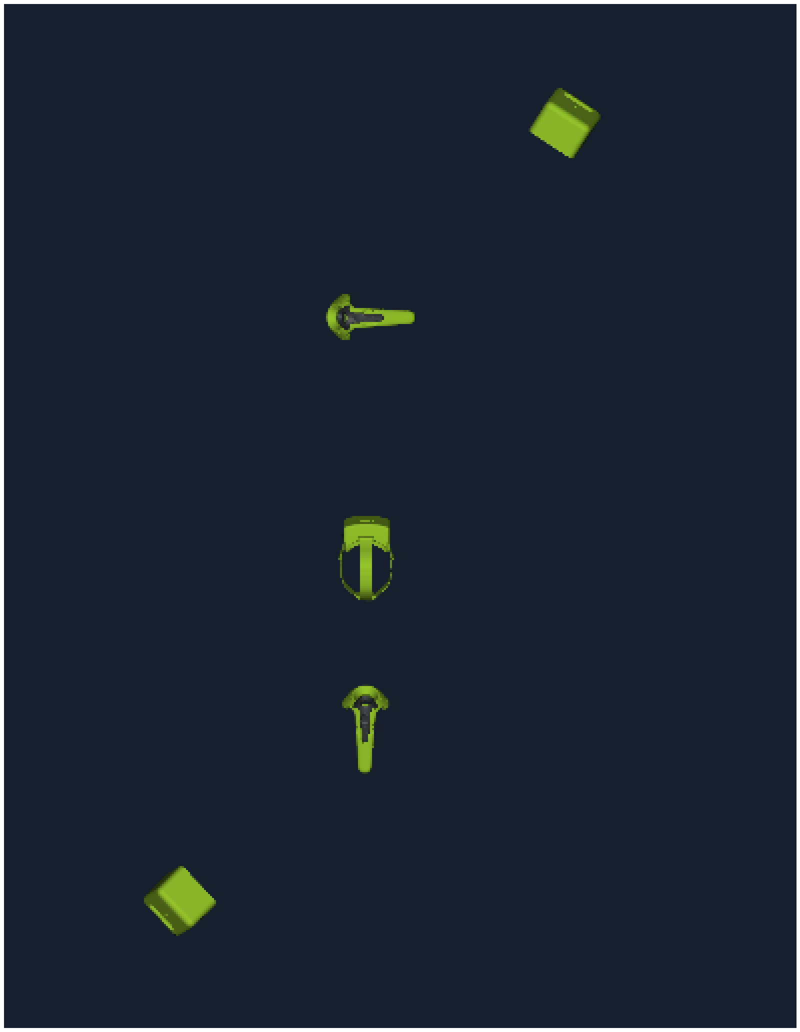


Figure 6 - HTC VIVE room configuration

3. Planning

3.1. Developing planning

This project counts with the collaboration of a student group from TUB (Technische Universität Berlin). In order for us to coordinate ourselves with the development of this project, we have divided it into three different stages:

3.1.1. Stage 1: Dummy version.

This first version will be focused on getting familiar with the software environment used in this project. Unity will be the software used to create all the VR scenarios. In stage 1, a first approach of a boat with water floating physics will be developed. The keyboard will be used to generate the input data to apply forces to the backside of the boat.

During this stage all the input data from the keyboard will be saved on an external file. Afterwards, this file will be used to move the opponent boat according the movement of the previous session.

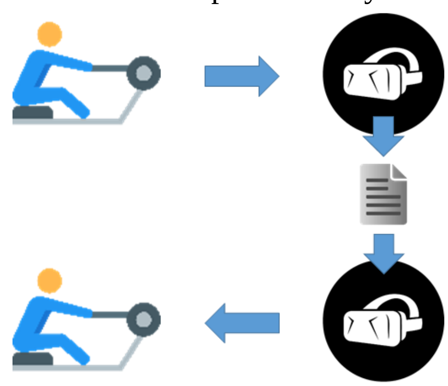


Figure 7 - Stage 1 game logic

Using this logic, it will be possible to use the same file logic, as soon as multiplayer mode is implemented. However, instead of files, it will be real-time data created by the ergometer which will be sent to a server and broadcasted to all the clients (opponents).

3.1.2. Stage 2: Using the ergometer as input data.

The goal in this state is to replace the keyboard as the input data and use real data from the rowing machine.

Augletics ergometer uses a tablet connected to the machine to control and receive all the data from the sensors. As Augletics has given us access to their API to this project, all these data will be used to control our scenario.

In this stage, a server will be implemented to receive the required data from the rowing machine and send to Unity to process and apply all the forces needed to move the virtual boat.

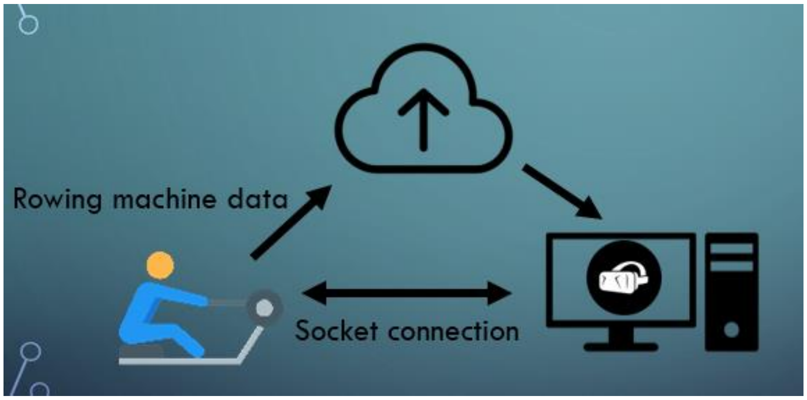


Figure 8 - Stage 2 data flow

In addition, an android app should be developed as a “man-in-the-middle” to receive data from the breathing sensor via Bluetooth and send it to Unity using the Wi-Fi local network. This will allow us to make different calculations with the breathing data merged with the ergometers’ data.

3.1.3. Stage 3: Multiplayer.

Finally, the last stage is the multiplayer feature. This last stage is not mandatory for this research as we want to compare VR performance against Non-VR performance. However, a multiplayer feature can be a relevant motivational point to include in VR. The situation of having an opponent´s boat approach the player will be a similar feeling to that of actual racing competitions.

The plan for this stage is to update the server from the last stage, implementing a lobby for game session, allowing other players to join and to exchange the movement data with other players. This way, the server will receive the data from all player’s ergometers and will update to all the clients with the new data of all the players.

3.2. Testing planning.

In order to determine if an immersive experience as VR can imply a better performance in rowing, a final test will be done to test it.

Here we can define two different fields to be studied, as this project not only intends to check the physical and technique performance, but also the psychology (Flow State) of the athlete

A previous study from our collaborators from TUB (Lukas Tetzlaff et al., Not published yet) used also VR to increase rowing experience. In their case, they added different challenging features in VR to check the motivational state of the subjects. To test that, they used the Flow State Scale (FSS) questionnaire.

As this project wants to test similar physiological aspects, the same flow state scale will be used. This questionnaire will be adapted as we are focusing on athletes instead of amateur users.

In addition to that, the objective performance has to be tested. The ergometer from Augletics can give us feedback about stroke technique, but only after every stroke. This is the reason why we will need to develop another application, to be able to receive this technique stroke data and to calculate the average of all the strokes. In the end of every testing scenario (VR and Non-VR) we need to have an overall qualification of all of the different metrics regarding technique. This will be an objective way to compare technique performance in different scenarios.

4. Development

4.1. Virtual environment.

A realistic virtual environment is key in accomplishing user immersion. Unity is the software used to create this virtual scenario. As we had two different scenes, one from TUB and the one I made, we had to choose only one to work from. The scenario from TUB was chosen because they already had the rowing machine and had some scripts in the scenario, which required the API from Augletics®. Apart from this, both scenarios had the same components which were developed in the same way.

The final project has the following six components:

4.1.1. Skybox

The Skybox is the background of the scenario. The one used is a free asset made from composing 4 different panoramic pictures to create a 360° landscape.

Figure 9 - Skybox preview

This skybox recreates a Norwegian landscape with snowed mountains. The mountains are represented far away from the player so that they cannot be seen to be static when the player moves.

4.1.2. Water

In order to use water physics, the *AQUAS* asset is used. This asset allows the application of flotation forces and to any 3D model with a rigid-body canvas.

This object needs to be set in a container. As such, a transparent squared “swimming pool” needs to be created using simple cube objects from unity and will be renamed as “Borders”.

Figure 10 - Water container

4.1.3. The boat.

This was a complex component, as it was impossible to find any 3D model of a racing rowing boat as a free asset. Instead, we had to create a new one from scratch. We created this model using Blender software. To get the final model, all the parts have been designed separately including the boat, the oars, the pivots and the riggers. Once all the parts have been implemented, we added the animation of a standard take moving the oars.

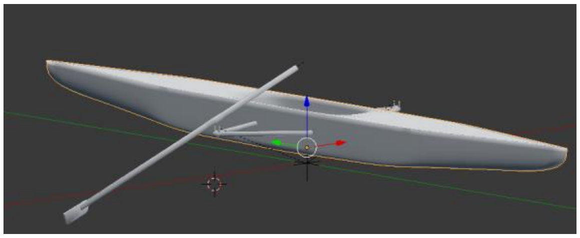


Figure 11 - 3D modeled boat in Blender

Finally, the model was ready to be imported into unity and have color added to it. To do this we created unity material objects with the desired color and added them to each part of the boat.

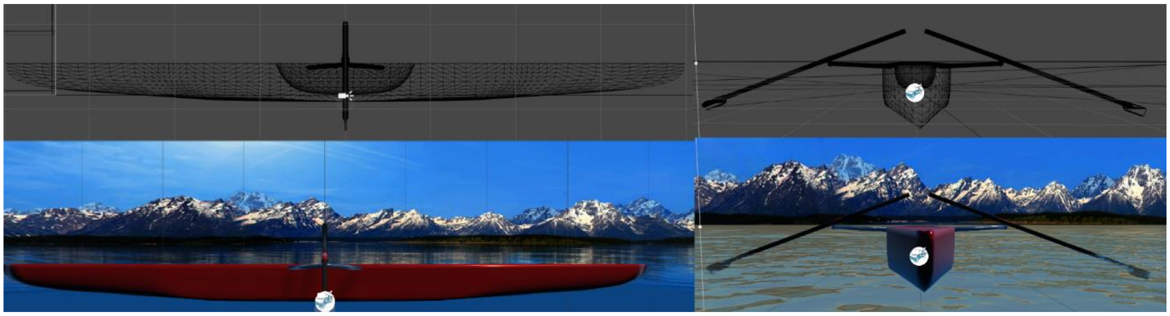


Figure 12 - Boat modeled imported to Unity

Finally, rigid-body property has been added to the boat. This will allow *AQUAS* to apply all the physics to our 3D modeled boat according to the boat shape.

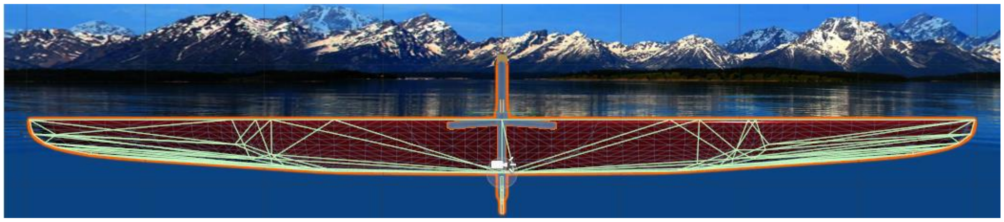


Figure 13 - Rigidbody canvas applied to the boat

The boat will be our player in the project, so we will add the camera to it in order to follow the boat once it is moving, resulting in a first person perspective. In this case, instead of the standard camera, the SteamVR asset will be attached to our player. This asset contains all the configuration to use the VR camera rig as the main camera. In addition, this asset includes the scripts required to use the controllers from HTC Vive as needed.

In this project, the controllers will be used to calibrate the rowing machine and to setup the VR environment aligned with the real ergometer in front of the user.

To move our boat, the data form of the rowing machine has to be received in Unity. This is what the script *LocalPlayer* does. This script attached to the boat asks the ergometer component for the required data to move the boat in the VR scenario, according to the real data produced by the rowing machine.

4.1.4. Ergometer

This is a code component only composed by two scripts. Both scripts will use the API from Augletics®. These scripts work together to create http websocket connection between Unity and the rowing machine, polling the route *@IPErgometer:5222/stroke* for the real data from current stroke on the ergometer. In this route, the ergometer is sharing the stroke power, the speed and the distance rowed. All this data is used to apply movement to the boat in VR and to run the animation of the oars, thus accomplishing a realistic movement in the virtual scenario.

4.1.5. User Interface

This component is composed by several scripts and is the core of the project. It not only shows to the user the lobby list room to join a pre-created game, or to start a new one. The most important feature of this component is the fact that it is the front part of the server.

It contains the logic to connect to the server to get into a new game and to update and get notifications of all the participants on the race. It also shows the countdown to the start of a race. Here is where the user can select and join a game, or create and host a new race, using only the VR headset to select the desired option by staring at specific parts of the UI.

Figure 14 - User Interfaces in Unity

These scripts are responsible for creating a websocket connection to the server to manage not only the lobby list, but the game session itself, polling the server for the movements of the opponent players to be able to update them with the new position in the VR scenario.

Moreover, it also controls the game state which can be *lobby*, *countdown*, *ingame* or *post*. While the status of the game is on *lobby*, it allows new participants to join in. During the *countdown* status, all of the received data from the ergometers will be cancelled to avoid cheating. In the *ingame* status, all the clients will be sending data from their ergometer to the server and this server will update with the new position of all the participant, broadcasting the data to all the clients in the game.

Finally the game will be closed when all the participants reach the end.

4.1.6. Checkpoints.

These components give feedback to the user about the distance rowed. It is a white line appearing every 50m with a numeric sign with the distance marker.

This feedback helps the user to know how much distance is remaining on the race to keep a better control of the rhythm and the intensity of the activity.

4.2. Server description.

This part was developed by our collaborators from TUB. The uses *npm*, which is a package manager for the JavaScript programming language. It is the default package manager for the JavaScript runtime environment *Node.js*. It consists of a command line client, also called *npm*, and an online database of public and paid-for private packages, the *npm* registry. The registry is accessed via the client, and the available packages can be browsed and searched via the *npm* website runs on the localhost over *Node.js*.

The webserver is accessible at http://localhost:3000 and the main used routes are:

GET /storages → Gets all the ID's of stored games. Returns: string[]

GET /storages/:id → Gets all the data packets of that stored game. Returns: IServerMessageDto[]

GET /games → Get names of open games. Returns: IGameDto[]

POST /games/:gameName → Joins a game lobby or creates one. Returns: IGameDto

PUT /games/:gameName → Leaves a game lobby and close it if there is no one left. Returns: "OK"

DELETE /games/:gameName → Closes a game lobby. Returns: "OK"

This server is in charge of locating different clients in a game after the required application. Once the game is running, the server will update all the clients with the new position of all the players (boats) of the race, sending *IServerMessageDto* if any of the clients sends updates. The field type determines the type of the payload property, timestamp is the time at which the package frame was generated. Clients will send *IClientMessageDto* when their data changes.

4.3. External digital coach software.

The digital coach from the rowing machine is able to give the user real-time information regarding 5 technique metrics on a visual 5 axis chart. This chart is easy to read for the user, but it is difficult to get a numeric grade of each metric, and in addition, it only shows the information of the last stroke.

To be able to objectively test the technical performance of every user at the end of a race, I needed to develop a new program in charge of getteing this data from the ergometer and store it. This allows to calculate the average of each metric counting will all the strokes made in the race.

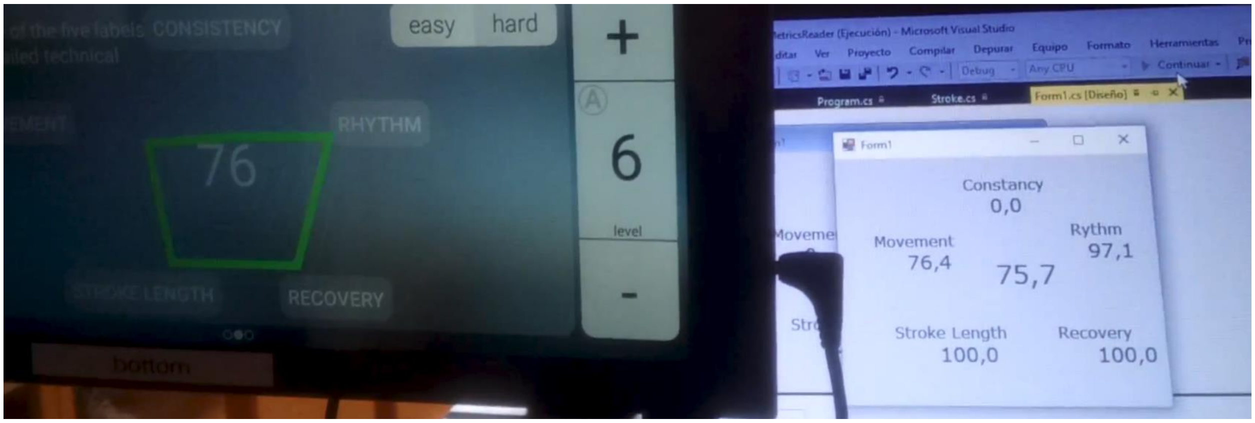


Figure 15 - Ergometer data reader during an experiment

This application is written in C# code using windows forms from Visual Studio IDE. This program has a main form with different labels and a timer. This timer will be triggered every 500 ms polling to the route *@IPErgometer:5222/stroke* for the ergometer data and downloading a Json file with the metrics of the stroke. After parsing it, the program will have values regarding constancy, movement, stroke length, recovery and rhythm of each stroke. Using the following formula, this data will be used to calculate the accumulative average of all this metrics at the end of the race.

$$Metric_{average} = Metric_{average} * \frac{Stroke_{number} - 1}{Stroke_{number}} + Metric_{new} * \frac{1}{Stroke_{number}}$$

As the program is polling the route every 500 ms, the data received could still be regarding the previous stroke, and consequently it may duplicate data from the same stroke. This is prevented by checking if the distance rowed is different from the previous stroke. If this is the case, the Json with the data of the new stroke will be downloaded and added to the formula. Otherwise it will never be added. The same check is applied when starting and finishing the race.

At the end of the race, the labels of the form will show the average grade of each technique metric.

4.4. Breathing sensor integration.

In the first approach, I developed an Android app to get the data from SweetZpot breathing sensor using a Bluetooth connection and then sending this data to Unity through a websocket connection to plot to breathing pattern on a small screen located inside the boat on the VR scenario. Due to time restrictions, and despite having the android App ready to use, I decided to use the source code from Sweetzpot during the testing sessions as it could give us the necessary data regarding breaths/min.

5. Testing

To do the experiment, we worked in collaboration with the NTNUI rowing team, which showed us how a standard rowing training looks like.

They have different training sessions: short session regarding technique and long sessions regarding endurance. For the technique session, they have only the feedback from the rowing machine and from their trainer.

The focus of this experiment is to test if there is any significant difference between training using VR against a Non-VR workout. In particular, technique performance is the most valuable point of this experiment, and for this reason, short trainings have been chosen as test sessions.

5.1. Test procedure

First of all, the participants were asked to read the test description carefully (See 8.1 – Questionnaires), where they were informed about the different scenarios tested in this experiment. All the metrics regarding rowing technique that will be recorded in the experiment were detailed as follows:

- Consistency: Same amount of strength and technique in every stroke (how similar are every stroke).
- Rhythm: Number of strokes per minute (20strk / min is a good rhythm).
- Movement: Body movement and coordination between arms and legs.
- Stroke length: Roll forward until your shins are in a vertical position.
- Recovery: Try to roll forward slowly and steadily.

Figure 16 - Athlete from NTNUI rowing in VR scenario

* Take into consideration that this is not a sprint race; we prefer good technique rather than speed. After reading the test description, the participant was asked to fill in a demographic questionnaire (See 8.1). Afterwards, test participants were performing a warm-up/baseline

phase, in which they were rowing 500m each, in non-VR and VR setup. During the non-VR setup, they saw all the available feedback including the metrics regarding their technique to check how they evolve according to their movement. The warming up session was also used to adjust the resistance level of the ergometer to a comfortable level.

After resting for 3 minutes, they were put into the test conditions. During the experiment two conditions were tested. A regular workout on the ergo-meter with distance covered as the only feedback variable for the participant, and a workout on the ergo-meter in the virtual environment. Here, participants were wearing a HTC Vive headset, and were put on the Virtual environment created on Unity to row.

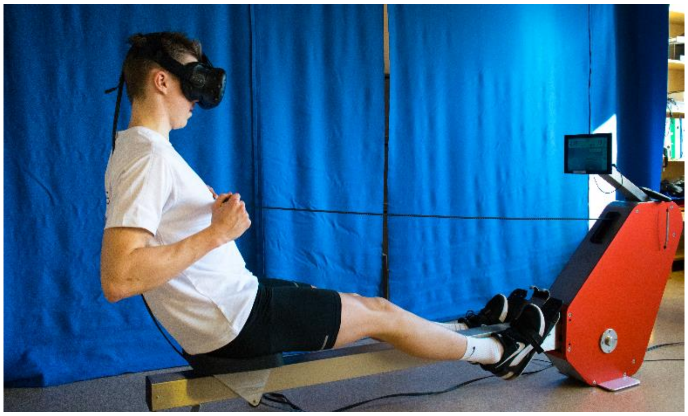


Figure 17 - Athlete rowing on Augletics ergometer

The feedback that was provided in the second scenario was distance markers every 50m, in addition to the steady movement on the lake depending on the force applied to the oars.

During both sessions, the participants needed to cover a distance of 500m rowing on the machine. The conditions of VR vs non-VR were randomized between participants.

The breathing rate was noted down every 50m, and was averaged afterwards over the session. After each of the two sessions, participants were asked to fill in the Activity Flow Scale questionnaire (Schwartz, S. J., Waterman, A. S., 2016), in order to assess their level of immersion, flow and satisfaction with the previous rowing experience.

Participants rated on a five-point Likert scale (Results were afterwards transferred as -2='Strongly Disagree', -1='Disagree', 0='Neutral', 1='Agree', 2='Strongly Agree'). In addition, participants were reporting on their emotional state after the exercise on a 9-point-SAM questionnaire, which contained the dimensions of valence, arousal, and dominance.

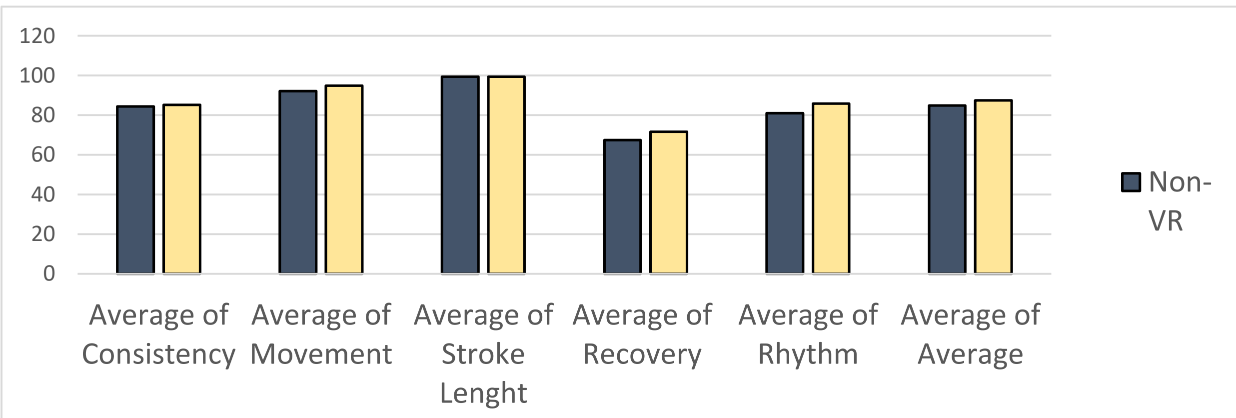
Finally, all the participants were asked for additional comments, suggestions of feedback to add.

5.2. Test Results

A total of 16 (5 males, 11 females) participants took part in this experiment. Of those participants, 13 of them stated to be experienced rowers, as members of the NTNUI rowing team, while the other 3 were non-regular rowers.

All of the subjects, except for one participant, stated to be involved in sports, training 9.4 hours a week on average. All the participants also stated to have little or no previous experience with VR devices.

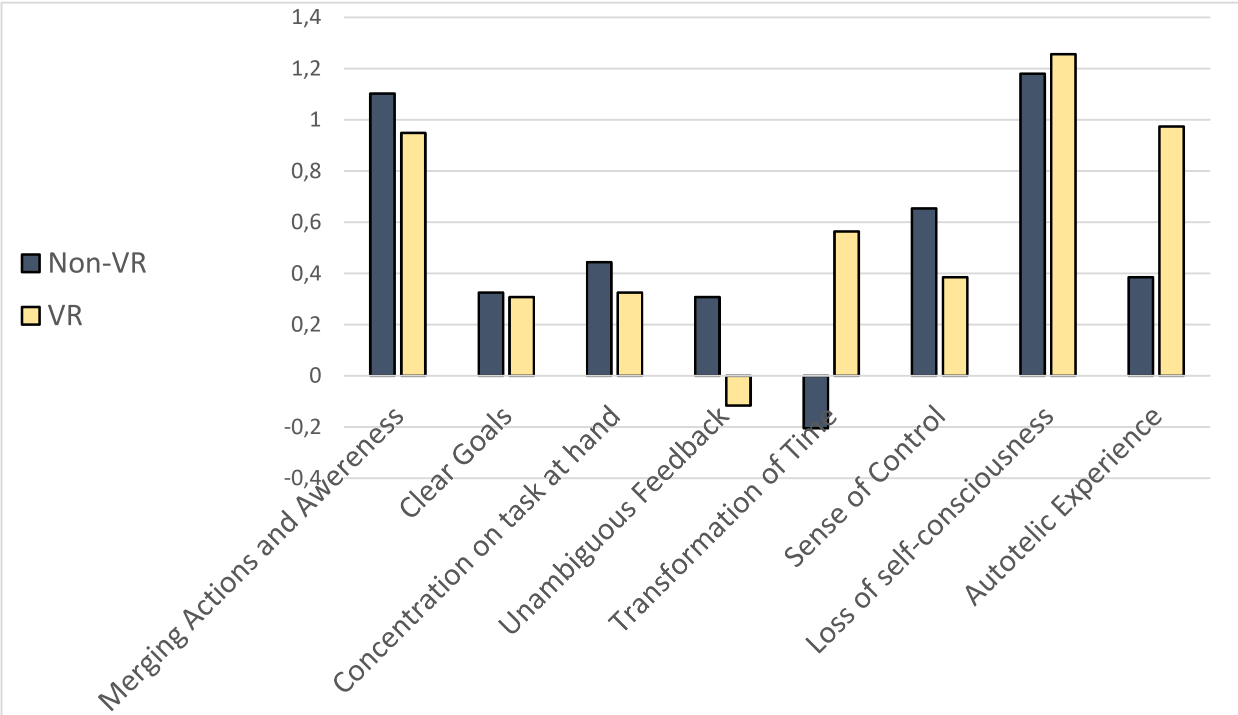
Investigating in to the objective measures taken during the experiment and the metrics derived based on those, it can be observed that values are generally slightly higher for the VR scenario than for the non-VR scenario.



Graph 1 – Technique metrics results

A running t-test over the data reveals significant differences during the VR and non-VR scenarios, especially in consistency ($\rho = 0.09$), recovery ($\rho = 0.09$), rhythm ($\rho = 0.006$), and for the overall average ($\rho = 0.0002$). In addition, the average breathing rate between both scenarios showed a significant difference ($\rho = 0.005$).

Regarding the results from the Flow State Scale questionnaires, it suggests a difference for 'Concentration on Task-at-Hand' ($\rho = 0.013$), 'Transformation of time' ($\rho = 0.005$), 'Autotelic Experience' ($p=0.0003$), and for the valence scale by the SAM questionnaire ($\rho = 0.006$). In addition, ratings on ’Motion Sicknesses (p=0.07), ’Quality of Experience’ (p=0.09) were significant on a level ρ ≤ 0:1.



Graph 2 – FSS results

The data from the questionnaires suggest a difference for ’Concentration on Task-at-Hand’ (ρ = 0.013), ’Transformation of time’ (ρ = 0.005), ’Autotelic Experience’ (p=0.0003), and for the valence scale by the SAM questionnaire (ρ = 0.006). In addition, ratings on ’Motion Sicknesses (p=0.07), ’Quality of Experience’ (p=0.09) were significant on a level ρ ≤ 0:1.

5.3. Discussion section

The results on the previous pages indicate that people seem to perform better in the VR scenario rather than Non-VR, especially regarding technical areas that are associated with the complex movement of rowing, and require rhythm and timing. The metric Rhythm is being described in the Augletics software as ’Pulling the handle quickly towards the chest, and then to roll slowly forward’, while Movement is described as ’extend your arms first and then move your upper body forward and only then begin to bend your knees and roll forward’.

This can be explained by linking the feedback given by the athletes who, in all the cases expressed having an experience much closer to rowing in the water, so they could concentrate more on what they were doing.

Similar results were found in another experiment which used a virtual reality environment warming up to improve the performance in the operating room (Calatayud et al., 2010), and significant improvement on precision performance was also observed.

In addition, participants also report different experiences on a subjective level with the two scenarios. The most significant variation is ‘autotelic experience’, defined as “an activity pursued for its own sake, based on the inherent intrinsic rewards gained from the process (as opposed to the outcome) of the experience.” (Csikszentmihalyi, 2014).

The next significant item is ‘transformation of time’ which is phrased as “when I engage in this activity I lose the track of time”, (PsycTests. Payne J. et al., 2011) which matches the feeling athletes stated after the session.

Additionally, participants reported on enjoying the VR experience more than the non-VR. They lost track of time more easily, and their autotelic experience was increased.

Surprisingly, they had a better ’concentration on the task’ during performing in the non-VR case. This contradicts with the objective measures, as they were performing more accurate in the VR scenario. This would have a relation to the fact than none of them had previous experiences with VR devices.

This was then, confirmed with the valence measure of the SAM scale, which showed an increase in the VR over the non-VR case. From the results we can make a general conclusion that there is a difference when working out in VR, versus a standard workout. This was only a first study to investigate possible effects.

Finally, the most common opinions and suggestions from the rowers were the need of having more feedback on VR, perhaps replacing the lines to buoys every 50m, as they have on the races, would be an improvement. Also adding sound to the scenario and the water trails, partnered with an improved movement of the oars, would create an even closer simulation to reality.

6. Conclusions

After finishing the experiments, a wide range of possibilities is created to continue with this project. All the feedback reported from the athletes should be implemented in the following steps. Having implemented the multiplayer feature, as the project has right now, it would be interesting to make a study about the social aspects in sports videogames, and in consequence, the motivational aspect of this.

Another good aspect to implement would be an eight people boat. Experienced rowers asked for this feature as one of the most important issues to develop. Synchronization is a key aspect of rowing and it is really difficult to be trained. A multiplayer boat could also save lots of time in the water if they had the possibility to train this aspect in indoor workouts.

However, a scientific paper will be published based on this project, as there appears to be some correlation between the VR immersion and the physical/technique performance.

Future studies could investigate how VR is affecting the rowers' performance when working on more exhausting zones during the workout. Also, what effects in VR could be improving the rower and their experience? Working out in a more social context, such as rowing versus friends or opponents, could be interesting to investigate.

According to this, some indoor-rowing championships could be organized using this technology. In fact, maybe this could be the future of some indoor sports.

Finally, I have the feeling that the future of video games and sports will tend to be more united than ever, involving more physical activity in videogames, while also incorporating more technological resources in the world of sports, perhaps resulting in some "hybrids", halfway between sports and videogames.

7. References

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8. Appendix

8.1. Test questionaries

Welcome and thank you for taking part in our project.

In this experiment we are going to test 2 different scenarios: Standard Rowing 500m race, and VR simulator 500m race. In order to get familiar with the rowing machine we will provide you with a warming up session of 8 minutes (4 minutes regular + 4 minutes with VR) on the ergometer. After the warming up session you will have 3 minutes to rest and then we will start with the different scenarios:

Standard Rowing Race: In this scenario you will test the rowing machine from Augletics for a 500m race. Take into consideration that this is not a sprint race; we prefer good technique rather than speed.

VR Simulator: In this scenario we will include the HTC Vive headset for a VR experience. The racing length will be 500m.

In all scenarios we are going to record some metrics regarding your technique. This metrics are:

- Consistency: Same amount of strength and technique in every stroke (how similar are every stroke).

- Rhythm: Number of strokes per minute (20strk / min is a good rhythm).

- Movement: Body movement and coordination between arms and legs.

- Stroke length: Roll forward until your shins are in a vertical position.

- Recovery: Try to roll forward slowly and steadily.

We will also record some biological data using the Sweetzpot chest breathing sensor.

At the end of each experiment we will give you a questionnaire in order to evaluate the scenaro.

Please note, not you are getting tested, but you are testing the system!

We hope you enjoy the experience and do your best!

Let’s row!

Number of participant:

Age:	
Gender:	◯ Female ◯ Male

On average, how many hours a week do you personally spend on doing sport? ________

How often do you do sport?

☐	☐	☐	☐	☐	☐
1 x a month	2 or more a month	1 x a week	2-3 x a week	4-5 x a week	Nearly every day

How experienced are you in rowing?	Not at all	◯	◯	◯	◯	◯	Very experienced
How experienced are you with Virtual Reality technologies (Cave, Head-Mounted Displays, e.g. HTC Vive)?	Not at all	◯	◯	◯	◯	◯	Very experienced

After this experiment, what is your opinion about this project?

Do you have any suggestion or comment to add?

Please make your evaluation now.

For the assessment of the experience, please fill out the following questionnaire. The questionnaire consists of pairs of contrasting attributes that may apply to the product. The circles between the attributes represent gradations between the opposites. You can express your agreement with the attributes by ticking the circle that most closely reflects your impression.

Example:

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

Please decide spontaneously. Don't think too long about your decision to make sure that you convey your original impression.

Sometimes you may not be completely sure about your agreement with a particular attribute or you may find that the attribute does not apply completely to the particular experience. Nevertheless, please tick a circle in every line.

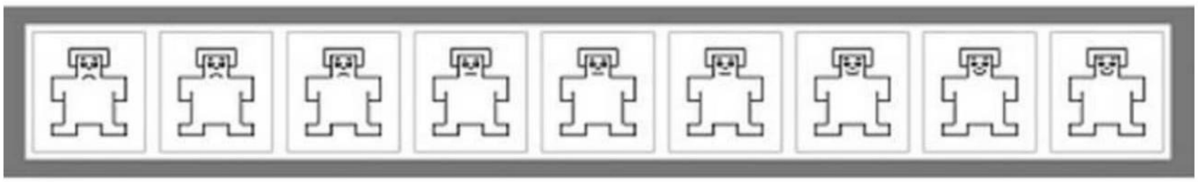
It is your personal opinion that counts. Please remember: there is no wrong or right answer!

Participant number:

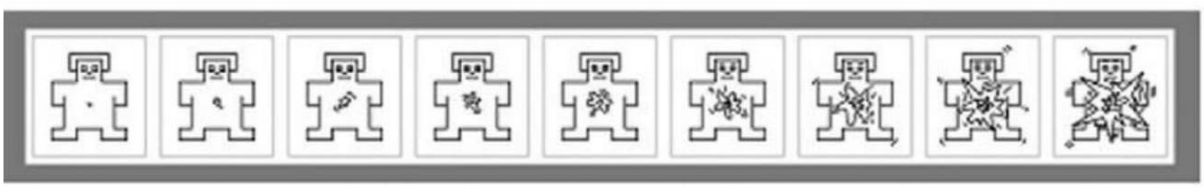
		Strongly Disagree	Disagree	Neither agree or disagree	Agree	Strongly Agree.
1	I performed automatically, without having to think about it.	○	○	○	○	○
2	I had a strong sense of what I wanted to accomplish.	○	○	○	○	○
3	My attention was focused entirely on what I was doing.	○	○	○	○	○
4	I had good feeling while I was performing about how well I was doing.	○	○	○	○	○
5	I lost my normal awareness of time.	○	○	○	○	○
6	I felt I had everything under control	○	○	○	○	○
7	I was not worried about what other might be thinking of me.	○	○	○	○	○
8	I really enjoyed the experience.	○	○	○	○	○
9	The experience was extremely rewarding.	○	○	○	○	○
10	I had not any kind of motion sickness during the experiment.	○	○	○	○	○
11	I did not feel exhausted after the experiment	○	○	○	○	○
12	Things just seemed to happen automatically.	○	○	○	○	○
13	I knew what I want to achieve.	○	○	○	○	○
14	It was no effort to keep my mind on what was happening.	○	○	○	○	○
15	It was really clear to me how my performance was going.	○	○	○	○	○
16	Time seemed to alter (either slows down or speeds up).	○	○	○	○	○
17	I felt as though I had everything under control.	○	○	○	○	○
18	I was not concerned with how I was presenting myself.	○	○	○	○	○
19	I did things spontaneously without having to think.	○	○	○	○	○
20	My goals were clearly defined.	○	○	○	○	○
21	I had total concentration.	○	○	○	○	○
22	The way time passed seemed to be different from normal.	○	○	○	○	○
23	I was not concerned with how others might be evaluating me.	○	○	○	○	○
24	The experience left me feeling great.	○	○	○	○	○
25	I did not feel dizzy after the experience.	○	○	○	○	○
26	The quality of the overall experience was great.	○	○	○	○	○
27	The **visual** quality of the experience was great. *(only for VR Experience)*	○	○	○	○	○

SAM/Emotions

Q1 - How happy or unhappy were you feeling during the scene? Please choose the image on the scale below that best corresponds with your feeling (the scale ranges from 1. very unhappy or sad to the left, to 9. extremely happy or joyful to the right)



Q2 - How calm or excited were you feeling during the scene? Please choose the image on the scale below that best corresponds with your feeling (the scale ranges from 1. very calm or sluggish to the left, to 9. very excited or aroused to the right)



Q3 - How controlled or in control were you feeling during the scene? Please choose the image on the scale below that best corresponds with your feeling (the scale ranges from 1. Very powerless, without control to the left, to 9. very dominant, fully in control to the right)